Summary of NASA OCT Science Instrument, Observatory and Sensor System (SIOSS) Technology Assessment Roadmap.

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Agenda

Office of Chief Technologist Technology Assessment A-STAR

Technology Assessment #8: Science Instruments, Observatories and Sensor Systems

Aero-Space Technology Area Roadmap (A-STAR)

July 2010, NASA Office of Chief Technologist (OCT) initiated an activity to create and maintain a NASA integrated roadmap for 15 key technology areas which recommend an overall technology investment strategy and prioritize NASA's technology programs to meet NASA's strategic goals.

Initial reports were presented to the National Research Council who are currently collecting public input and preparing reviews of each Roadmap.

Roadmaps will be updated annually and externally reviewed every 4 years consistent with the Agency's Strategic Plans.

Technology Assessment Areas

TA1:	Launch Propulsion Systems
TA2:	In-Space Propulsion Systems
TA3:	Space Power and Energy Storage Systems
TA4:	Robotics, Tele-robotics, and Autonomous Systems
TA5:	Communication and Navigation Systems
TA6:	Human Health, Life Support and Habitation Systems
TA7:	Human Exploration Destination Systems
TA8:	Scientific Instruments, Observatories, and Sensor Systems
TA9:	Entry, Descent, and Landing Systems
TA10:	Nanotechnology
TA11:	Modeling, Simulation, Information Technology, and Processing
TA12:	Materials, Structural & Mechanical Systems, and Manufacturing
TA13:	Ground and Launch Systems Processing
TA14:	Thermal Management Systems
TA15:	Aeronautics

Goals and Benefits

- External credibility for planned NASA technology programs
- Internally credible and transparent process to ensure all Mission Directorate (MD) priorities are included
- Develop clear NASA technology portfolio recommendations
- Establish current prioritization of alternate technology paths
- Reveal interrelationships of various technologies and associated investments
- Interrelationships and coordination with other agencies
- Broad-based input from non-government parties
- Transparency in government technology investments

Charge to TA Teams

Review, document, and organize the existing roadmaps and technology portfolios.

Collect input from key Center subject matter experts, program offices and Mission Directorates.

Take into account:

- US aeronautics and space policy;
- NASA Mission Directorate strategic goals and plans;
- Existing Design Reference Missions, architectures and timelines; and
- Past NASA technology and capability roadmaps.

Technology Assessment Content

- Define a breakdown structure that organizes and identifies the TA
- Identify and organize all systems/technologies involved in the TA using a 20-year horizon
- Describe the state-of-the-art (SOA) for each system
- Identify the various paths to achieve performance goals
- Identify NASA planned level of investment
- Assess gaps and overlaps across planned activities
- Identify alternate technology pathways
- Identify key challenges required to achieve goals

Technology Assessment #8:

Science Instruments, Observatories and Sensor Systems (SIOSS)

SIOSS technology needs & challenges are traceable to:

- specific NASA science missions planned by the Science Mission Directorate (‘pull technology’) or
- emerging measurement techniques necessary to enable new scientific discovery (‘push technology’).

TA8 Roadmap Team

Rich Barney (GSFC), Division Chief, Instrument Systems and Technology Division.

Co-chaired 2005 NASA Science Instruments and Sensors Capability Roadmap.

Phil Stahl (MSFC), Senior Optical Physicists

Optical Components Technical Lead for James Webb Space Telescope;

Mirror Technology Days in the Government;

Advanced Optical Systems SBIR Subtopic Manager;

2005 Advanced Observatories and Telescopes Capability Roadmap.

Upendra Singh (LaRC), Chief Technologist, Engineering Directorate.

Principal Investigator for NASA Laser Risk Reduction Program (2002-2010)

Dan Mccleese (JPL), Chief Scientist

Principal Investigator of Mars Climate Sounder instrument on Mars Reconnaissance Orbiter.

Jill Bauman (ARC), Associate Director of Science for Mission Concepts.

Lee Feinberg (GSFC), Chief Large Optics System Engineer

JWST OTE Manager.

Co-chaired 2005Advanced Telescopes and Observatories Capability Roadmap.

Technology Assessment Breakdown Structure (TABS)

The most difficult task was defining a TABS.

SIOSS is a merger of the 2005 NASA Advanced Planning and Integration Office (APIO) roadmaps:

Advanced Telescopes and Observatories (ATO), and

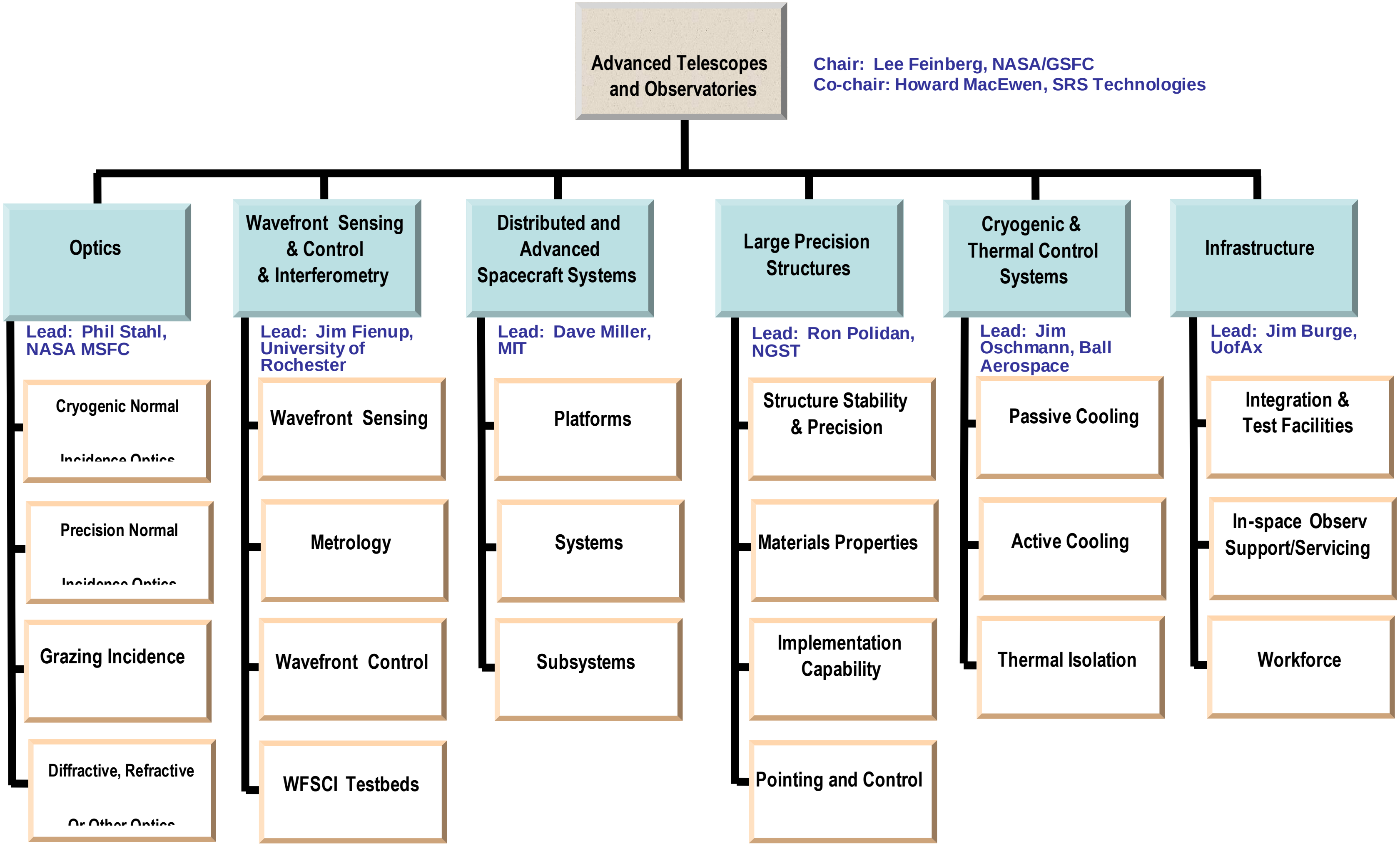
Science Instruments and Sensors (SIS).

But, ATO and SIS had approached Capability Assessment with from two entirely different methodologies.

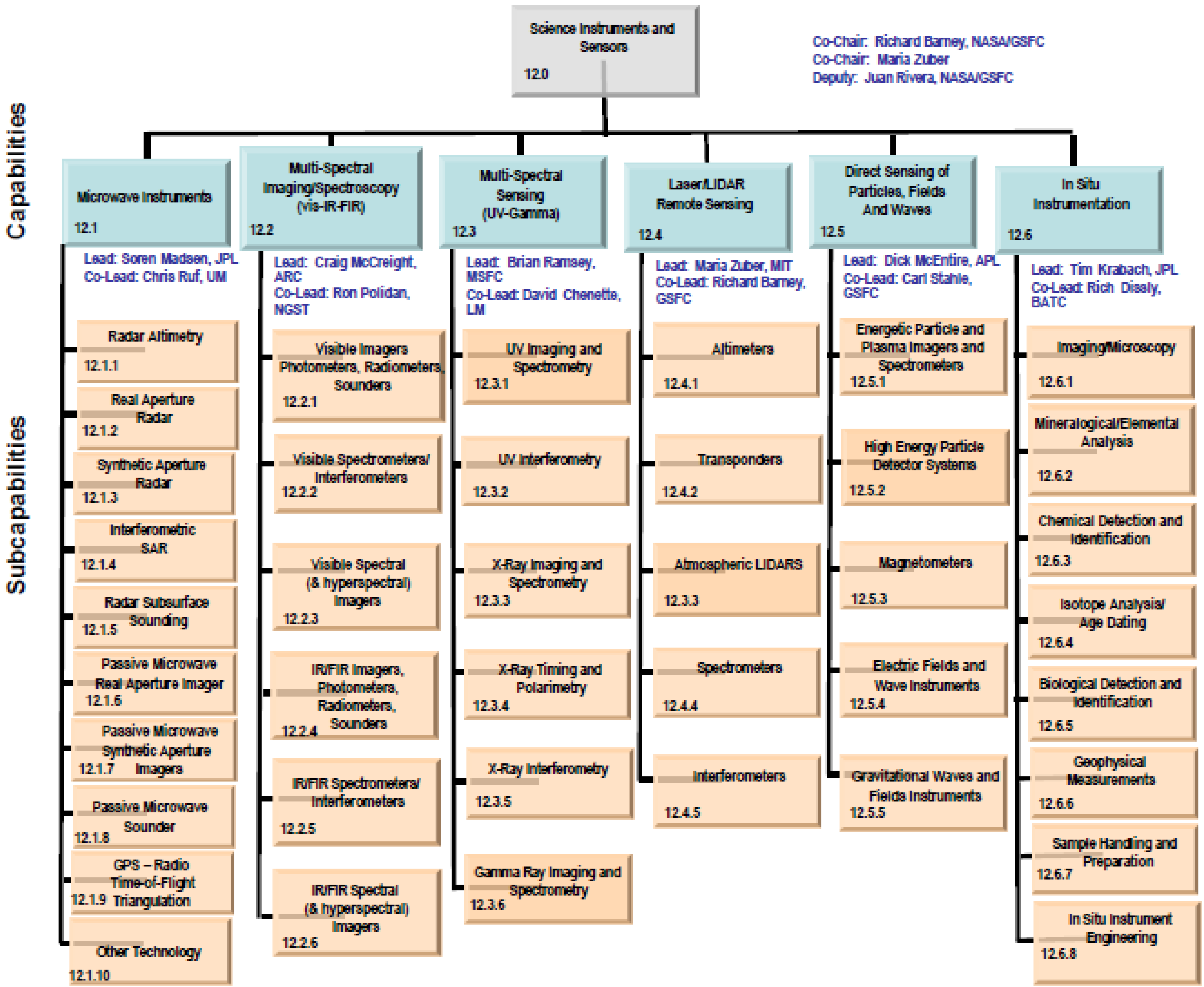
ATO was technology driven.

SIS was measurement driven.

ATO Capability Breakdown Structure



SIS Capability Breakdown Structure



The level 2-breakdown lists the most important instrument classes within the individual sub-capabilities.

SIOSS TABS

We defined a three-tier TABS based on the name we were given.

Science Instrument technologies generate photons or convert photons into science data. They may be stand-alone sharing a common spacecraft bus or integrated with an observatory.

Observatory technologies collect, concentrate, and/or transmit photons.

Sensor System technologies create data by collecting and sensing particles, fields, waves, chemicals, or biological samples and are stand-alone systems not requiring an observatory.

TA8: Technology Area Breakdown Structure

- 8.1 Science Instruments, Observatories & Sensor Systems
  - 8.1 Remote Sensing Instruments/Sensors
    - 8.1.1 Detectors & Focal Planes
    - 8.1.2 Electronics
    - 8.1.3 Optical Components
    - 8.1.4 Microwave/Radio
    - 8.1.5 Lasers
    - 8.1.6 Cryogenic/Thermal
  - 8.2 Observatories
    - 8.2.1 Mirror Systems
    - 8.2.2 Structures & Antenna
    - 8.2.3 Distributed Aperture
  - 8.3 In-Situ Instruments/Sensors
    - 8.3.1 Particles
    - 8.3.2 Fields & Waves
    - 8.3.3 In-Situ

TA8: Technology Area Breakdown Structure

8.0 Science Instruments, Observatories & Sensor Systems

8.1 Remote Sensing Instruments/Sensors

(8.1.1) Detectors and Focal Planes

8.1.1.1 Large Format Arrays
8.1.1.2 Spectral Detectors
8.1.1.3 Polarization Sensitive Det.
8.1.1.4 Photon-Counting Det.
8.1.1.5 Radiation-Hardened Det.
8.1.1.6 Sub-Kelvin High-Sensitivity Det.

(8.1.2) Electronics

8.1.2.1 Radiation Hardened
8.1.2.2 Low Noise
8.1.2.3 High Speed

(8.1.3) Optical Components

8.1.3.1 Starlight Suppression
8.1.3.2 Active Wavefront control
8.1.3.3 Optical Components
8.1.3.4 Advanced Spectrometers/Instruments

(8.1.4) Microwave & Radio Transmitters & Receivers

8.1.4.1 Integrated Radar T/R Modules
8.1.4.2 Integrated Radiometer Receivers

(8.1.5) Lasers

8.1.5.1 Pulsed Lasers
8.1.5.2 CW Lasers

(8.1.6) Cryogenic/Thermal

8.1.6.14-20K Cryo-Coolers for Space
8.1.6.2 Sub-Kelvin Coolers

8.2 Observatories

(8.2.1) Large Mirror Systems

8.2.1.1 Grazing Incidence
8.2.1.2 Normal Incidence

(8.2.2) Large Structures & Antenna

8.2.2.1 Passive Ultra-Stable Structures
8.2.2.2 Deployable/Assembled Tel. Support Structure and Antenna
8.2.2.3 Active Control

(8.2.3) Distributed Apertures

8.2.3.1 Formation Flying

8.3 In-Situ Instruments/Sensors

(8.3.1) Particles

8.3.1.1 Energetic Particle Det. (>30keV-NMeV)
8.3.1.2 Plasma Det. (<1eV-30keV)
8.3.1.3 Magnetometers (DC & AC)

(8.3.2) Fields & Waves

8.3.2.1 EM Field Sensors
8.3.2.2 Gravity-Wave Sensors

(8.3.3) In-Situ

8.3.4.1 Sample Handling, Preparation, and Containment
8.3.4.2 Chemical and Mineral Assessment
8.3.4.3 Organic Assessment
8.3.4.4 Biological Detection & Characterization
8.3.4.5 Planetary Protection

SIOSS Team employed a two-step process

First step was to review existing governing documents (such as Decadal Surveys, roadmaps, and the science plans) for each of the four NASA Science Mission Directorate (SMD) divisions:

Astrophysics,	Earth Science,
Heliophysics,	Planetary.

From these, specific technology needs were identified that enable or enhance planned and potential future missions.

Detailed listings of technology needs for each SMD division were tabulated and then reviewed and refined by individual mission and technology-development stakeholders.

Astrophysics Technology Needs

National Academy 2010 Decadal Report recommended missions and technology-development programs, (with need date):

- *Wide Field Infrared Survey Telescope (WFIRST), 2018*
- *Explorer Program, 2019/2023*
- *Laser Interferometer Space Antenna (LISA), 2024*
- *International X-ray Observatory (IXO), mid/late 2020s*
- *New Worlds Technology Development Program, mid/late 2020s*
- *Epoch of Inflation Technology Development Program, mid/late 2020s*
- *U.S. Contribution to the JAXA-ESA SPICA Mission, 2017*
- *UV-Optical Space Capability Technology Development Program, mid/late 2020s*
- *TRL3-to-5 Intermediate Technology Development Program*

All can be enhanced or enabled by technology development to reduce cost, schedule, and performance risks.

Astrophysics Technology Needs

Astrophysics requires advancements in 5 SIOSS areas:

- Detectors and electronics for X-ray and UV/optical/infrared (UVOIR);
- Optical components and systems for starlight suppression, wavefront control, and enhanced UVOIR performance;
- Low-power sub 10K cryo-coolers;
- Large X-ray and UVOIR mirror systems; and
- Multi-spacecraft formation flying, navigation, and control.

Additionally, Astrophysics missions require other technologies:

- Affordable volume and mass capacities of launch vehicles to enable large-aperture observatories and mid-capacity missions;
- Terabit communication; and
- Micro-Newton thrusters for precision pointing and formation-flying navigation control.

Table 2.2.1.1 – 1 Summary of Astrophysics Technology Needs						
Mission	Technology	Metric	State of Art	Need	Start	TRL6
WFIRST	NIR detectors	Pixel array Pixel size	2k x 2k 18 μm	4k x 4k 10 μm	2012	2014
UVOTP Push	Detector arrays: Low noise	Pixel QE UV QE Visible Rad Hard	2k x 2k	4k x 4k > 0.5 90-300 nm > 0.8 300-900 nm 50 to 200 kRad	2012	2020
NWTP Push	Photon counting arrays	Pixel array visible Visible QE Pixel array NIR	512 x 512 80% 450-750 nm 128 x 128	1k x 1k >80% 450-900 nm 256 x 256	2011	2020
SPICA ITP Push	Far-IR detector arrays	Sens. (NEP W/√Hz) Wavelength Pixels	1e-18 > 250μm 256	3e-20 35-430μm 1k x 1k	2011	2015 2020
IXO Push	X-ray detectors	Pixel array Noise QE Frame rate	 10-15 e^- RMS 100 kHz@2e^-	40 x 40 TES 2-4 e^- RMS >0.7 0.3-8 keV 0.5 - 1 MHz@2e^-	2011	2015
WFIRST IXO	Detector ASIC	Speed @ low noise Rad tolerance	100 kHz 14 krad	0.5 - 1 MHz 55 krad	2011	2013
NWTP	Visible Starlight suppression: coronagraph or occulter	Contrast Contrast stability Passband Inner Working Angle	> 1 x 10^{-9} --- 10%, 760-840 nm 4 λ/D	< 1 x 10^{-10} 1 x 10^{-11}/image 20%, at *V*, *I*, and *R* 2λ/D – 3λ/D	2011 2011	2016 2020
NWTP	Mid-IR Starlight suppres: interferometer	Contrast Passband mid-IR	1.65 x 10^{-5}, laser 30% at 10 μm	< 1 x 10^{-7}, broadband > 50% 8μm	2011 2011	2016 2020
NWTP UVOTP	Active WFSC; Deformable Mirrors	Sensing Control (Actuators)	λ/10,000 rms 32 x 32	< λ/10,000 rms 128 x 128	2011	2020
IXO	XGS CAT grating	Facet size; Throughput	3x3 mm; 5%	60x60mm; 45%	2010	2014
Various	Filters & coatings	Reflect/transmit; temp			2011	2020
Various	Spectroscopy	Spectral range/resolve			2011	2020
SPICA IXO	Continuous sub-K refrigerator	Heat lift Duty cycle	< 1 μW 90 %	> 1 μW 100 %	2011	2015
IXO Push	Large X-ray mirror systems	Effective Area HPD Resolution Areal Density; Active	0.3 m2 15 arcsec 10 kg/m2; no	>3 m2 (50 m2) <5 arcsec (<1 as) 1 kg/m2; yes	2011	2020 (30)
NWTP UVOTP Push	Large UVOIR mirror systems	Aperture diameter Figure Stability Reflectivity kg/m2 $/m2	2.4 m < 10 nm rms --- >60%, 120-900 nm 30 kg/m2 $12M/m2	3 to 8 m (15 to 30 m) <10 nm rms >9,000 min >60%, 90-1100 nm Depends on LV <$1M/m2	2011	2020 (30)
WFIRST	Passive stable structure	Thermal stability	Chandra	WFOV PSF Stable	2011	2014
NWTP	Large structure: occulter	Dia; Petal Edge Tol	Not demonstrated	30-80 m; <0.1mm rms	2011	2016
NWTP UVOTP Push	Large, stable telescope structures (Passive or active)	Aperture diameter Thermal/dynamic WFE Line-of-sight jitter kg/m2 $/m2	6.5 m 60 nm rms 1.6 mas 40 kg/m2 $4 M/m2	8 m (15 to 30 m) < 0.1 nm rms 1 mas <20 (or 400) kg/m2 <$2 M/m2	2011	2020 (30)
LISA NWTP	Drag-Free Flying Occulter Flying	Residual accel Range Lateral alignment	3x10^{-14} m/s^2/√Hz	3x10^{-15} m/s^2/√Hz 10,000 to 80,000 km ±0.7 m wrt LOS	2011	2016
NWTP Push	Formation flying: Sparse & Interferometer	Position/pointing #; Separation	5cm/6.7arcmin 2; 2; 2 m	 5; 15–400-m	2011	2020
LISA Push	Gravity wave sensor Atomic interferometer	Spacetime Strain Bandpass	N/A	1x10^{-21}/√Hz, 0.1-100mHZ	2013	2019
Various	Communication	Bits per sec		Terra bps		2014

SIOSS Team employed a two-step process

Second step was consolidating the detailed technology needs for each mission directorate into broad categories. For example, many missions across all directorates require new or improved detector technology.

These broad categories were then organized into a Technology Area Breakdown Structure (TABS).

Technology Area 8.2 Observatory

Major challenges include:

- X-ray Grazing Incidence Mirror Systems
- UV-Vis-IR Normal Incidence Mirror Systems
- Large Ultra-stable Structures
- Large Deployable/Assembled Structures
- Control of Large Structures
- Distributed Aperture / Formation flying

Technologies support 3 applications:

- X-ray astronomy,
- UVOIR astronomy, and
- Radio / microwave antenna.

Most important metric for all observatories is cost per square meter of aperture.

Table 2.2.2.2-1: Observatory Technology Challenges

	Technology Metric	State of Art	Need	Start	TRL6	Mission
8.2.1 Large Mirror Systems	8.2.1.1 Grazing Incidence					
	1 to 100 keV FWHM resolution	10 arcsec	<5 arcsec	2011	2014	FOXSI-3
	Aperture diameter FWHM resolution Areal density; Areal cost	0.3 m2 15 arcsec 10 kg/m2	>3 m2 <5 arcsec	2011	2020	IXO
	Aperture diameter FWHM angular resolution Areal density (depends on LV) Active Control	0.3 m2 15 arcsec 10 kg/m2 No	>50 m2 <1 arcsec 1 kg/m2 (depend LV) Yes	2011	2030	Push GenX
	8.2.1.2 Normal Incidence					
	Size & polarization Areal density	Planck ~20 kg/m2	1.6 m <6 kg/m2	2011 2018	2020 2024	ITP 3DWinds
	Aperture diameter Figure Stability (dynamic & thermal) Reflectivity Areal density (depends on LV) Areal cost	2.4 m < 10 nm rms --- >60%, 120-900nm 240 kg/m2 $12M/m2	3 to 8 m <10 nm rms >9,000 min >60%, 90-900 nm 20 (or 400) kg/m2 <$2M/m2	2011	2020	NWTP UVOTP
	Aperture diameter Areal density (depends on LV) Areal cost	6.5 m 50 kg/m2 $6M/m2	15 to 30 m 5 (or 100) kg/m2 < $0.5M/m2		2030	Push EL-ST
8.2.2 Large Structures & Antenna	8.2.2.1 Passive Ultra-Stable Structures					
	Thermal stability	Chandra	WFOV PSF Stability	2011	2014	WFIRST
	Aperture diameter Thermal/dynamic stability Line-of-sight jitter WFE Areal density (depends on LV) Areal cost	6.5 m 60 nm rms 1.6 mas 40 kg/m2 $4 M/m2	8 m 15 nm rms 1 mas <20 (or 400) kg/m2 <$2 M/m2	2011	2020	NW/UVO
	8.2.2.2 Deployable/Assembled Telescope Support Structure and Antenna					
	Antenna aperture Antenna aperture Surface figure	5 m 1.5 mm rms	6 m > 10 m <0.1 mm rms	2013 2016	2019 2023	ACE SCLP
	Boom length Stiffness Pointing stability		≥ 20 m 10^7 N m^2 0.005 arcsec roll/3 min	2011	2014	GRIPS ONEP SWOT
	Occulter diameter	Few cm	30 to 100 m	2011	2020	NWTP
	Aperture diameter	6.5 m	8 m	2011	2020	NW/UVO
	Aperture diameter	6.5 m	15 to 30 m		2030	EL-ST
	8.2.2.3 Active Control					
	Occulter pedal control Occulter modal control Boom tip control		< 0.5 deg < 0.1 mm rms ~0.5 deg	2011 2012	2020 2014	NWTP GRIPS
	Aperture diameter Aperture diameter Thermal/dynamic stability Line-of-Sight jitter WFE Areal density (depends on LV) Areal cost	6.5 m 6.5 m 60 nm rms 1.6 mas 40 kg/m2 $4 M/m2	8 m 15 to 30 m 15 nm rms 1 mas <20 (or 400) kg/m2 <$2 M/m2	2011	2020 2030	NW/UVO Push EL-ST
8.2.3 Distributed	8.2.3.1 Formation Flying					
	Range		10,000 to 80,000 km	2013	2016	LISA
	Separation control Lateral alignment Relative position Relative pointing	2 m 5 cm rms 6.7 arcmin rms	100 to 400 ±0.1 m ±0.7 m wrt LOS < 1 cm rms < 1 ±0.1 arcsec	2011	2015 2024 2030	ONEP Occulter NWTP Push

Table 2.2.2.2-1: Observatory Technology Challenges

	Technology Metric	State of Art	Need	Start	TRL6	Mission
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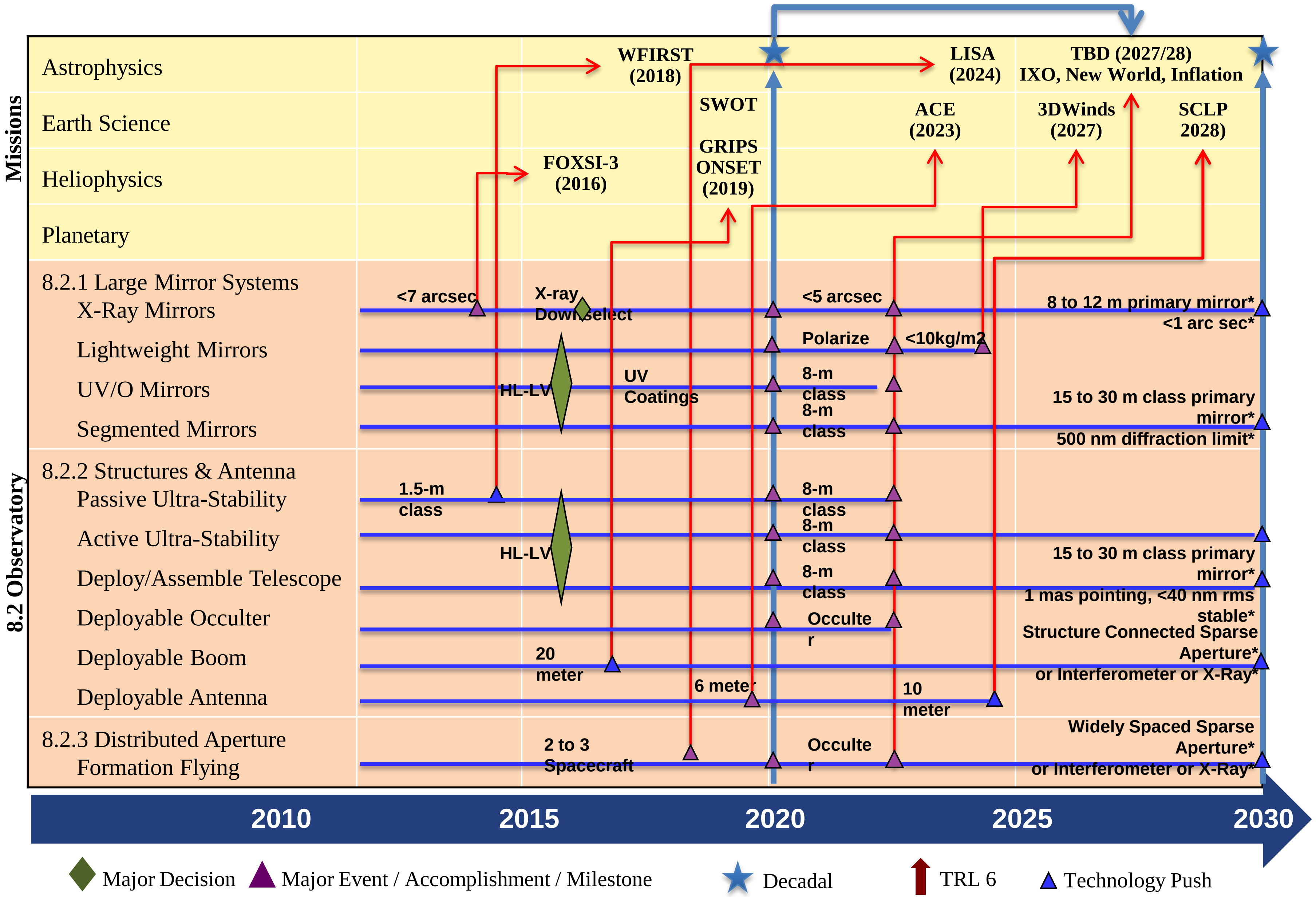
	Aperture diameter FWHM resolution Areal density; Areal cost	0.3 m2 15 arcsec 10 kg/m2	>3 m2 <5 arcsec	2011	2020	IXO
	Aperture diameter FWHM angular resolution Areal density (depends on LV) Active Control	0.3 m2 15 arcsec 10 kg/m2 No	>50 m2 <1 arcsec 1 kg/m2 (depend LV) Yes	2011	2030	Push GenX
	8.2.1.2 Normal Incidence					
	Size & polarization Areal density	Planck ~20 kg/m2	1.6 m <6 kg/m2	2011 2018	2020 2024	ITP 3DWinds
	Aperture diameter Figure Stability (dynamic & thermal) Reflectivity Areal density (depends on LV) Areal cost	2.4 m < 10 nm rms --- >60%, 120-900nm 240 kg/m2 $12M/m2	3 to 8 m <10 nm rms >9,000 min >60%, 90-900 nm 20 (or 400) kg/m2 <$2M/m2	2011	2020	NWTP UVOTP
	Aperture diameter Areal density (depends on LV) Areal cost	6.5 m 50 kg/m2 $6M/m2	15 to 30 m 5 (or 100) kg/m2 < $0.5M/m2		2030	Push EL-ST
8.2.2 Large Structures & Antenna	8.2.2.1 Passive Ultra-Stable Structures					
	Thermal stability	Chandra	WFOV PSF Stability	2011	2014	WFIRST
	Aperture diameter Thermal/dynamic stability Line-of-sight jitter WFE Areal density (depends on LV) Areal cost	6.5 m 60 nm rms 1.6 mas 40 kg/m2 $4 M/m2	8 m 15 nm rms 1 mas <20 (or 400) kg/m2 <$2 M/m2	2011	2020	NW/UVO
	8.2.2.2 Deployable/Assembled Telescope Support Structure and Antenna					
	Antenna aperture Antenna aperture Surface figure	5 m 1.5 mm rms	6 m > 10 m <0.1 mm rms	2013 2016	2019 2023	ACE SCLP
	Boom length Stiffness Pointing stability		≥ 20 m 10^7 N m^2 0.005 arcsec roll/3 min	2011	2014	GRIPS ONEP SWOT
	Occulter diameter	Few cm	30 to 100 m	2011	2020	NWTP
	Aperture diameter	6.5 m	8 m	2011	2020	NW/UVO
	Aperture diameter	6.5 m	15 to 30 m		2030	EL-ST
	8.2.2.3 Active Control					
	Occulter pedal control Occulter modal control Boom tip control		< 0.5 deg < 0.1 mm rms ~0.5 deg	2011 2012	2020 2014	NWTP GRIPS
	Aperture diameter Aperture diameter Thermal/dynamic stability Line-of-Sight jitter WFE Areal density (depends on LV) Areal cost	6.5 m 6.5 m 60 nm rms 1.6 mas 40 kg/m2 $4 M/m2	8 m 15 to 30 m 15 nm rms 1 mas <20 (or 400) kg/m2 <$2 M/m2	2011	2020 2030	NW/UVO Push EL-ST
8.2.3 Distributed	8.2.3.1 Formation Flying					
	Range		10,000 to 80,000 km	2013	2016	LISA
	Separation control Lateral alignment Relative position Relative pointing	2 m 5 cm rms 6.7 arcmin rms	100 to 400 ±0.1 m ±0.7 m wrt LOS < 1 cm rms < 1 ±0.1 arcsec	2011	2015 2024 2030	ONEP Occulter NWTP Push

Push Technologies: 8.2 Observatories

Technology	Description
8.2 Observatories	
Synthetic Aperture Imaging Lidar (SAIL)	Synthetic Aperture Imaging Lidar (SAIL) for hyper-resolution imaging and 3D ranging (range imaging). SAIL methods could map dynamics of planetary surfaces on Mars (polar caps), Titan (moving landscapes), and even on Europa much more efficiently than current single beam or multi-beam approaches. SAIL may be a method worth pursuing for ICESat-3 in the 2020's to rapidly build up 3D geodetic maps of the ice covered surfaces of Earth
Super High-Resolution Imaging of High-Energy Photons	The technology need is to build a large area (much larger than current optics) high energy optic and then have it fly it formation with the imaging spacecraft
Radar Arrays	Wideband active electronically steered array radar with lightweighted antennae
Precision Interferometry	Requires CW single-frequency and frequency-stabilized lasers for space (GSFC applications so far are pulsed). Digital techniques including coded modulation for time-of-flight resolvable interference, and flexible in-flight changes. Time-Domain Interferometry (LISA's equal-path-length synthesis techniques).
Hyper-Resolution Visible-NIR	Hyper-resolution Visible-NIR imaging using lightweighted optics in the 1-1.5m class (5 cm/pixel class)
K-Band Radar	Compact K-band imaging and sounding radars (nadir and sidelooking) for planetary sciences (small antennae)
Conductive Carbon Nanotubes	Spectacular new material for the fabrication of lightweight antennas could be enabled by the unbelievable conductivity of individual carbon nanotubes.
Deployable Large Aperture Telescopes	Ultra low mass/volume large deployable large aperture telescopes (>2 meter) for direct detection LIDAR. Concepts include inflatable fresnel, deployable reflector and petal-based techniques.
High stability optical platforms	Includes optical benches, telescopes, etc, requiring passive thermal isolation for temperature stability. Hydroxide or silicate bonding for precision alignment capability and dimensional stability. Precision materials such as Silicon Carbide and single crystal silicon, Zerodur

8.2 Observatories Roadmap



Observatory Technology Needs

Regardless of whether the incumbent is 0.5 m or 5 m, the driving need is larger aperture with similar or better performance.

The technologies for achieving performance are

- the ability to manufacture and test large-mirror systems;
- the structure's ability to hold the mirror in a stable, strain-free state under the influence of anticipated dynamic and thermal stimuli; and,
- for extra-large apertures, a method to create the aperture via deployment, assembly, or formation flying – where formation-flying technology is simply an actively controlled virtual structure.

One non-telescope application is the manufacture, deployment, in-plane and formation-flying control of an external-occulting starshade to block starlight for exo-planet observation.

Top Mirror Technology Challenges

Present to 2016 (Near Term)

Low-Cost, Large-Aperture Precision Mirrors

- UV and optical lightweight mirrors, 5 to 10 nm rms, <$2M/m2, <30kg/m2
- X-ray: <5 arc sec resolution, < $0.1M/m2 (surface normal space), <3 kg/m2

2017 to 2022 (Mid Term)

High-Contrast Exoplanet Technologies

- High-contrast nulling and coronagraphic algorithms and components (1x10^-10, broadband); occulters (30 to 100 meters, < 0.1 mm rms)

Ultra-Stable Large Aperture UV/O Telescopes

- > 50 m2 aperture, < 10 nm rms surface, < 1 mas pointing, < 15 nm rms stability, < $2M/m2

Other Technology Assessment Observatory Needs

The ability to produce large aperture observatories depends upon advances in other technology assessment areas:

- volume and mass capacities of launch vehicles;
- validated performance models that integrate optical, mechanical, dynamic, and thermal models for telescopes, structures, instruments, and spacecraft to enable the design and manufacture of observatories whose performance requirements are too precise to be tested on the ground;
- new materials and design concepts to enable ultra-stable very large space structures;
- terabit communication; and
- autonomous rendezvous and docking for on-orbit assembly of very large structures.

Benefits to Other National Needs

SIOSS Technologies have potential benefit for a wide range of national needs, organizations and agencies:

- National Atmospheric and Oceanic Administration (NOAA)
- Department of Defense (DoD)
- Commercial Space Imaging Companies
- Department of Homeland Security (DHS)
- Department of Energy
- Department of Health and Human Services
- Food and Drug Administration
- Environmental Protection Agency

Summary

Science Instruments, Observatories, and Sensor System Technology Area 8 Roadmap draft is complete and currently undergoing review by the National Research Council.

Top Technology Challenges Defined.

Individual roadmaps for remote sensing Instruments/sensors, observatories, and in-situ instruments/sensors defined with both push and pull technologies highlighted.